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# Fresh Water Generation from Aquifer-Pressured Carbon Storage

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# Fresh Water Generation from Aquifer-Pressured Carbon Storage

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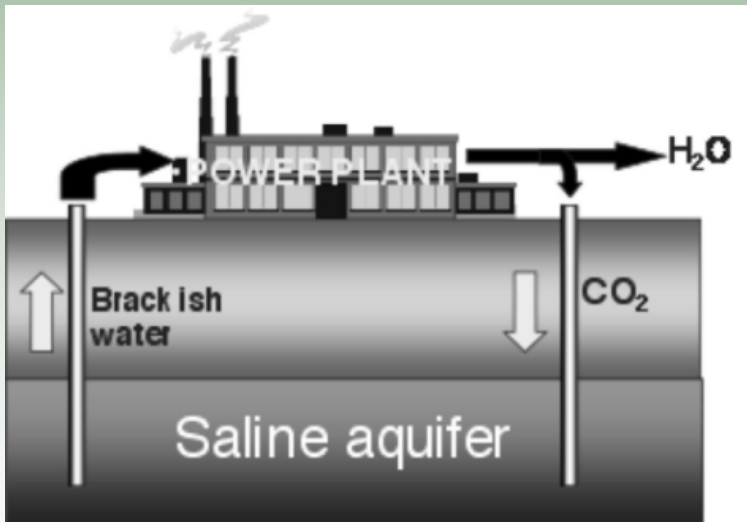
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Ninth Annual Conference on Carbon Capture & Sequestration

# Can we use the pressure associated with sequestration to make brine into fresh water?

- This project is establishing the potential for using brine pressurized by Carbon Capture and Storage (CCS) operations in saline formations as the feedstock for desalination and water treatment technologies including reverse osmosis (RO) and nanofiltration (NF).



- Possible Products:
  - Drinking water
  - Cooling water
  - Extra aquifer space for CO<sub>2</sub> storage



# Chemistry and cost for generating fresh water are the principal issues

- Chemistry
  - Is it feasible to treat formation brines by reverse osmosis (RO)?
  - What are the limits to salinity or untreatable components?
- Cost
  - Can existing pressure (due to CO<sub>2</sub> injection) help?
  - What would the treatment costs be?

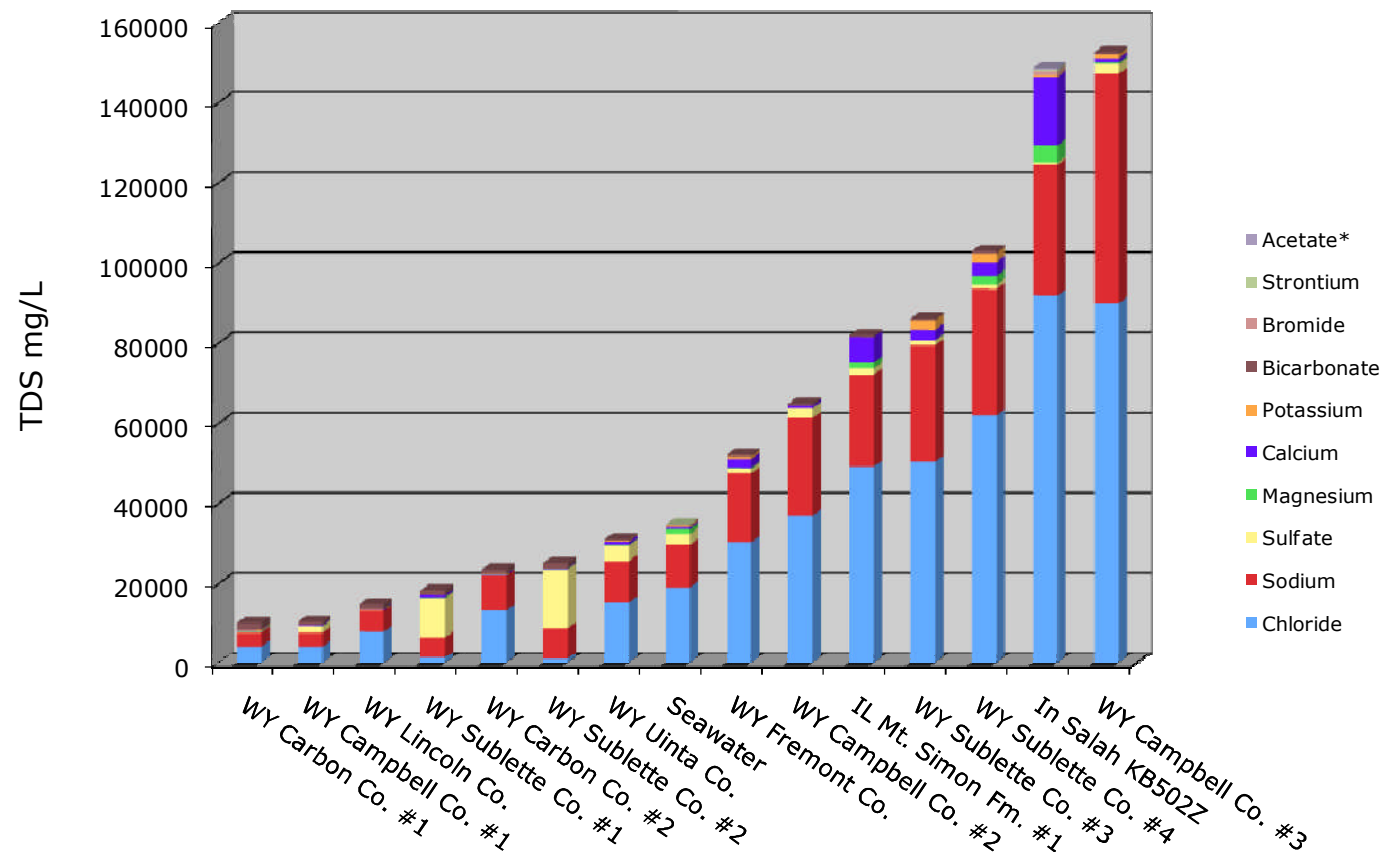
# Seawater Is a Point of Comparison

- It is an Na-Cl dominated brine with a TDS of  $\sim 36,000$  mg/L
- Many subsurface brines are compositionally similar to seawater, and likely trace directly or indirectly to a partial seawater origin
- There is extensive industrial experience in treating seawater with reverse osmosis
- The subsurface brine equivalent of seawater (Na-Cl brine with the same TDS) does differ from regular seawater in minor ways (less biota, reducing rather than oxidizing)

# Chemistry of Saline Formation Waters

- The most important parameter for RO is TDS (Total Dissolved Salt content)
  - Lower limit (regulatory, for CO<sub>2</sub> disposal): 10,000 mg/L
  - Upper limit in nature: about 400,000 mg/L
- Three types of saline formation waters are common, defined according to dominant cations and anions:
  - Na-Cl (example, seawater): widespread, TDS ranges from less than that of seawater (36,000 mg/L) to ~350,000 mg/L TDS
  - Na-Ca-Cl: widespread, TDS is generally above that of seawater, extending all the way up to ~400,000 mg/L TDS
  - Na-Cl-SO<sub>4</sub> (“high sulfate”, mainly from Rocky Mountain basins region): TDS ranges from less than that of seawater to ~110,000 mg/L

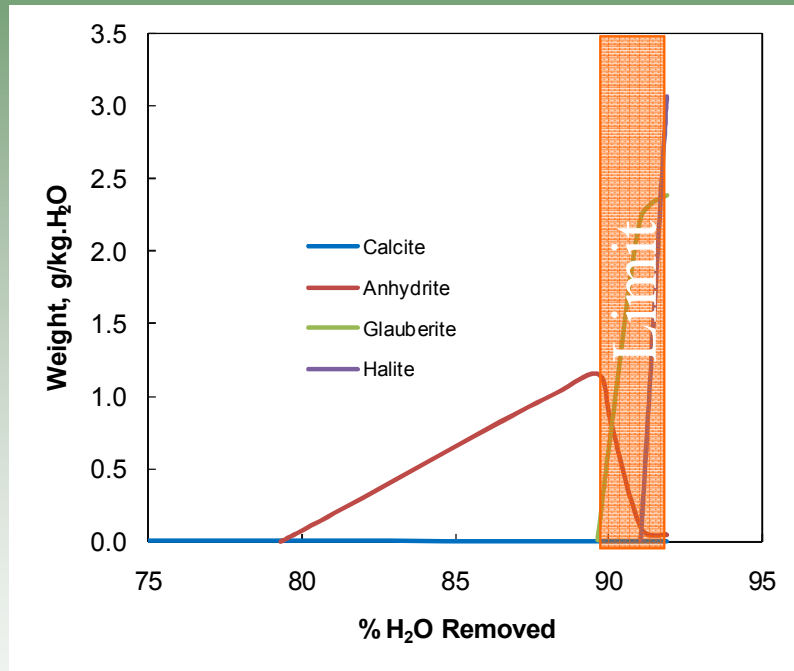
# Subsurface Brine Catalog (Shown: 10,000-160,000 mg/L TDS)



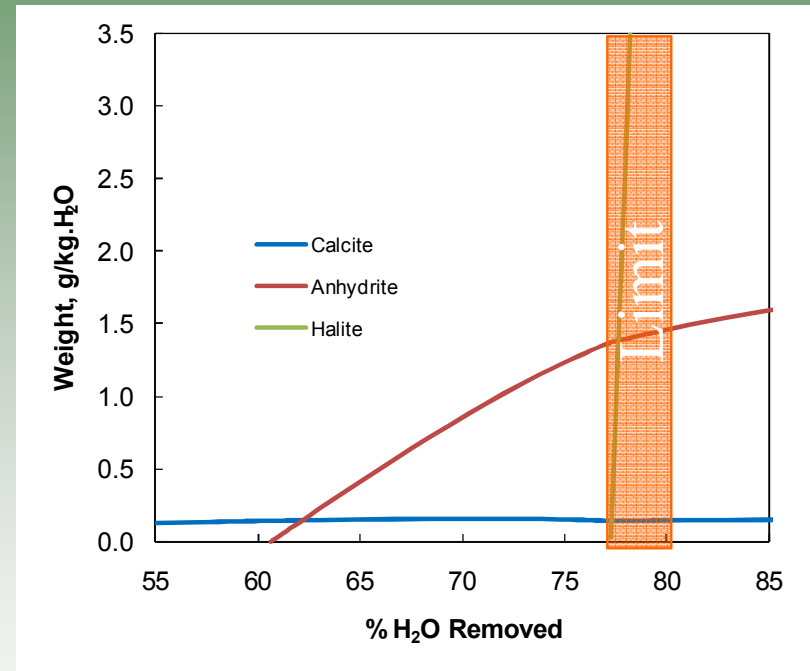
# Thermodynamic modeling using Pitzer's equations has been used to evaluate treatability of saline formation waters

- Model the removal of water using the EQ3/6 code (Extended UNIQUAC equations are available as an alternative to Pitzer's)
- Runs were made for 25, 50, 70, and 90°C (40-50°C is the likely operational temperature)
- Calculate the potential for mineral scaling on the feed/residual side
- Calculate the osmotic pressure ( $\pi$ ) on the feed/residual side:
  - This limits the applicability of reverse osmosis (RO), because a pressure difference  $\Delta p$  must be applied to overcome the osmotic pressure difference  $\Delta\pi$  (RO produces nearly pure water, for which  $\pi$  is essentially zero)
  - Conventional RO membranes will support  $\Delta p$  of 1200 psi. Newer ones will support 1500 psi.

Mineral scaling at 50°C: Seawater brine (left) vs. WY Sublette Co. #3 brine (Nugget Formation, Big Sky CSP site, right).  
Formation of halite (NaCl) imposes a firm limit.

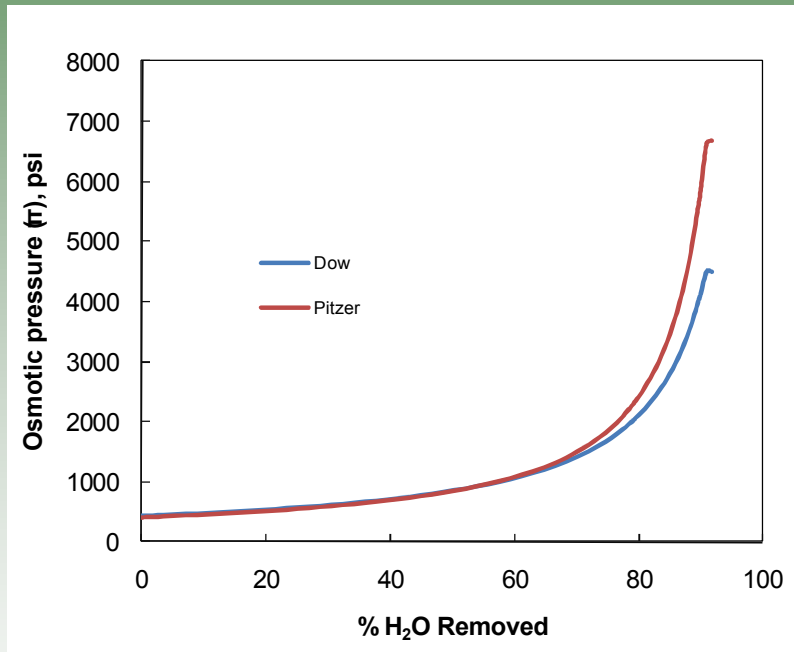


Seawater brine,  
TDS = 35,928 mg/L

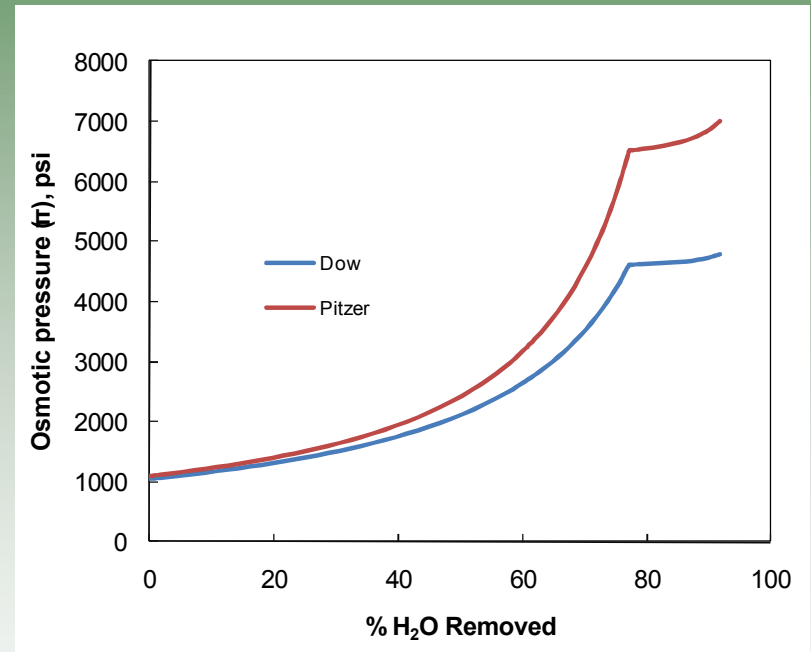


WY Sublette Co. #3,  
TDS = 85,926 mg/L

Osmotic pressure at 50°C: Seawater brine (left) vs. WY Sublette Co. #3 brine (Nugget Formation, Big Sky CSP site, right). The Dow equation (a widely-used industry formula) is inaccurate at high concentration.

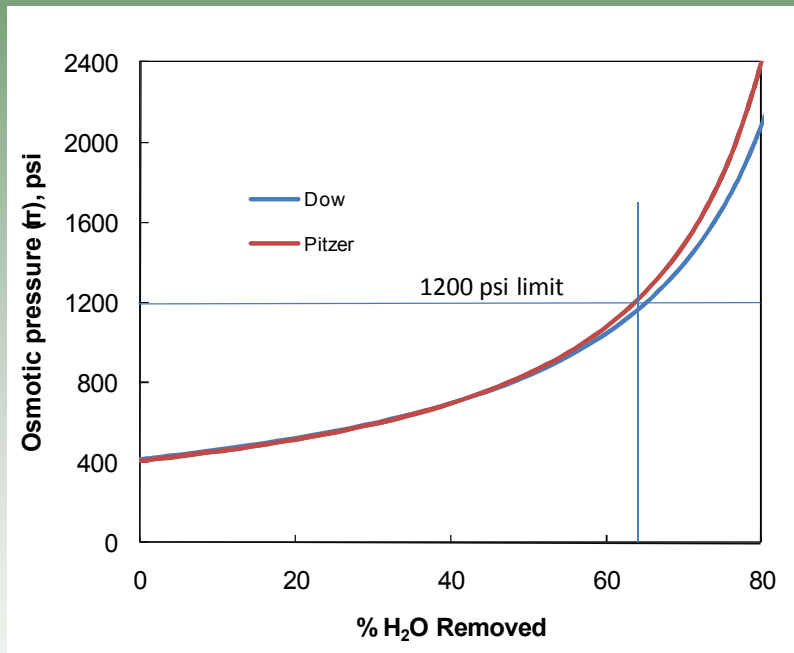


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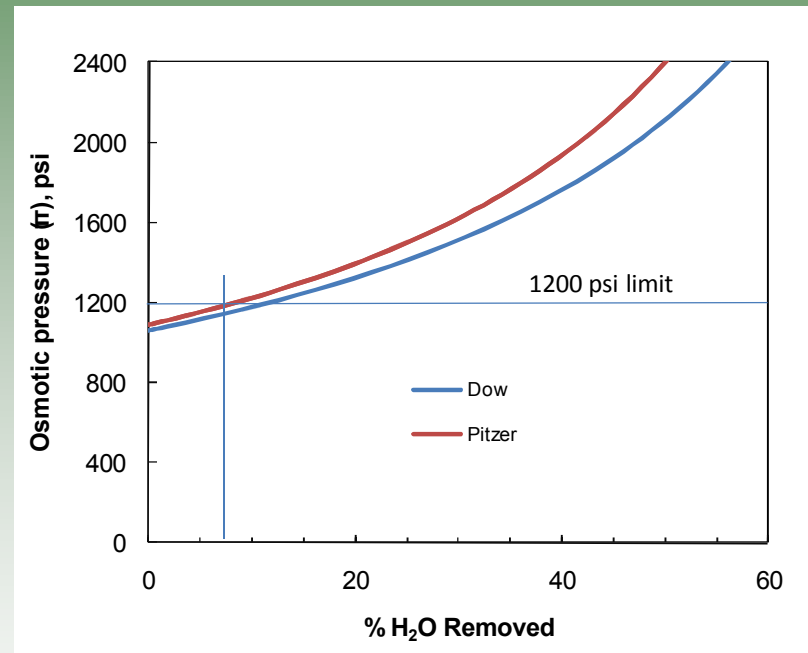


WY Sublette Co. #3,  
TDS = 85,926 mg/L

Osmotic pressure at 50°C: Seawater brine (left) vs. WY Sublette Co. #3 brine (right). The 1200 psi limit of conventional RO membranes limits water recovery. *Osmotic pressure is more limiting than mineral scaling.*



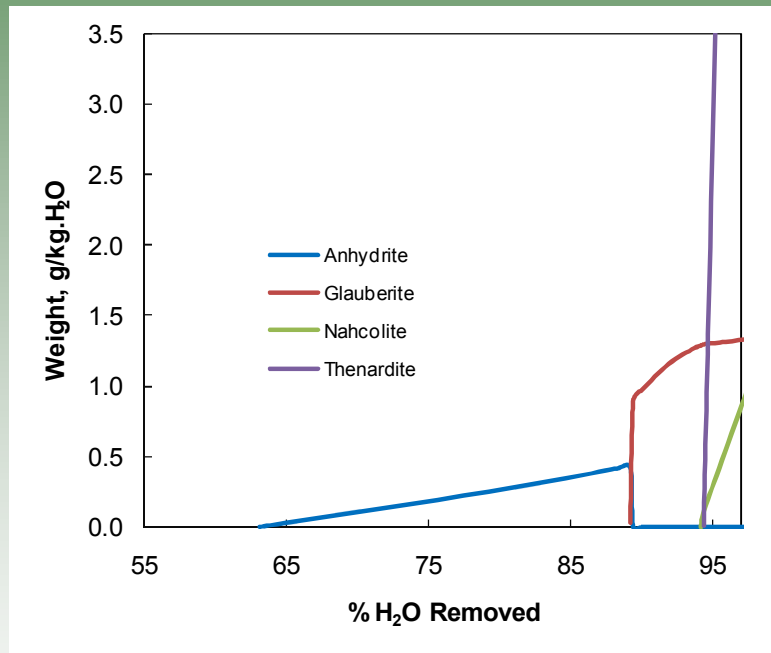
Seawater  
(Na-Cl) brine  
TDS = 35,928 mg/L



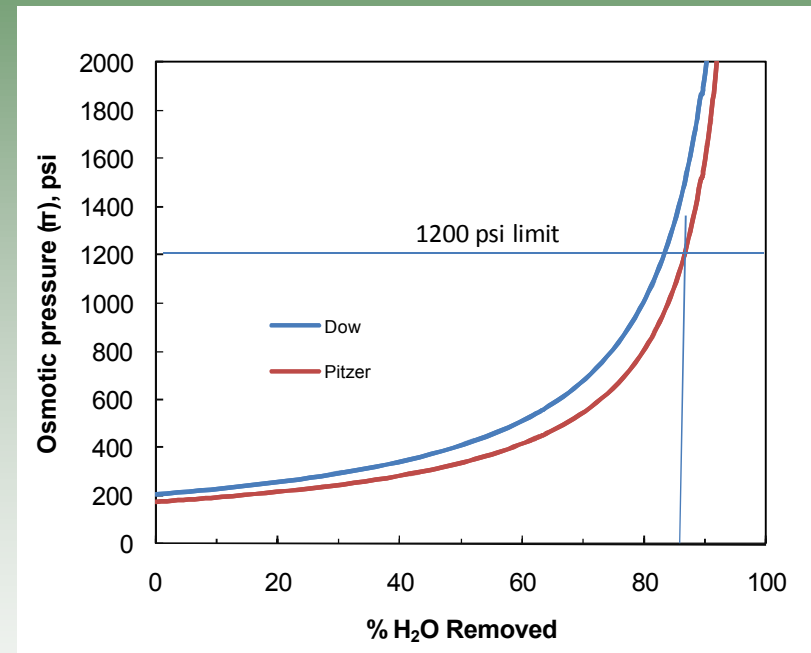
WY Sublette Co. #3  
(Na-Cl) brine  
TDS = 85,926 mg/L



Mineral scaling (left) and osmotic pressure (right) at 50°C: WY Sublette Co. #2 (Na-Cl-SO<sub>4</sub> brine, Tensleep Formation, *below* the Nugget Formation, TDS = 24,501 mg/L). *This would be a superb candidate for RO – especially in a structural trap.*

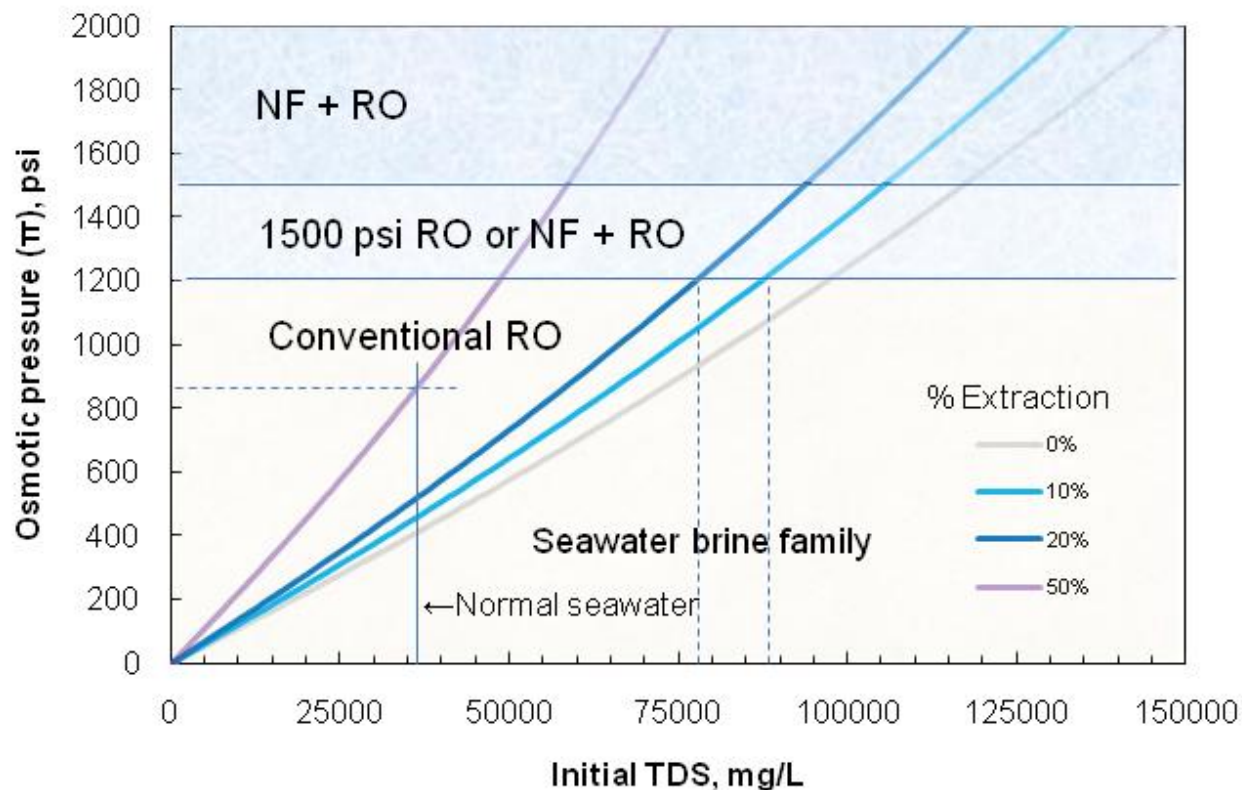


Mineral scaling

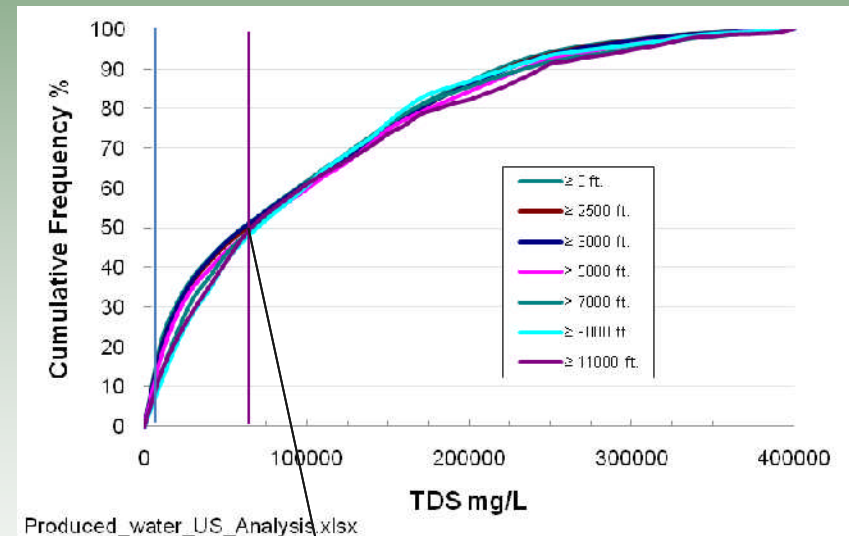
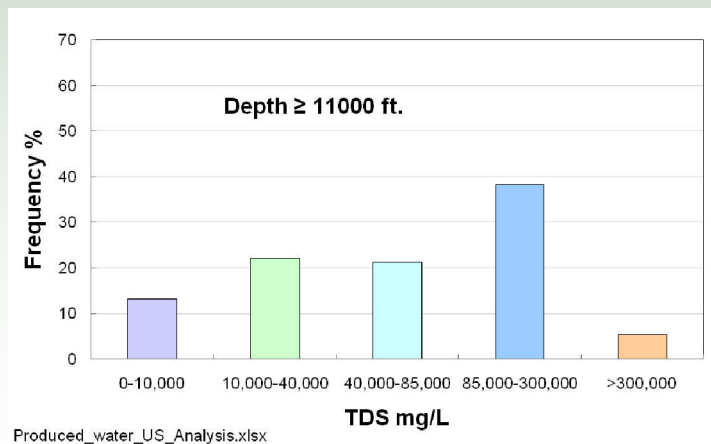
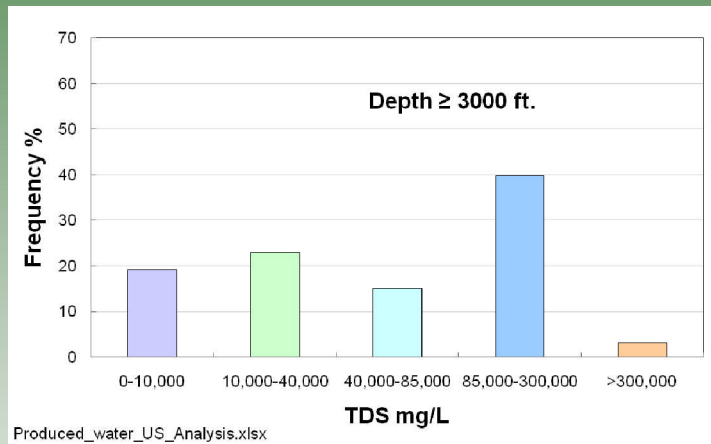


Osmotic pressure

Osmotic pressure at 50°C of seawater family (Na-Cl) brine for 0, 10, 20, and 50% water extraction, as a function of initial TDS. 10% extraction is feasible by conventional RO for TDS  $\leq$  88,000 mg/L, 20% for TDS  $\leq$  77,000 mg/L.

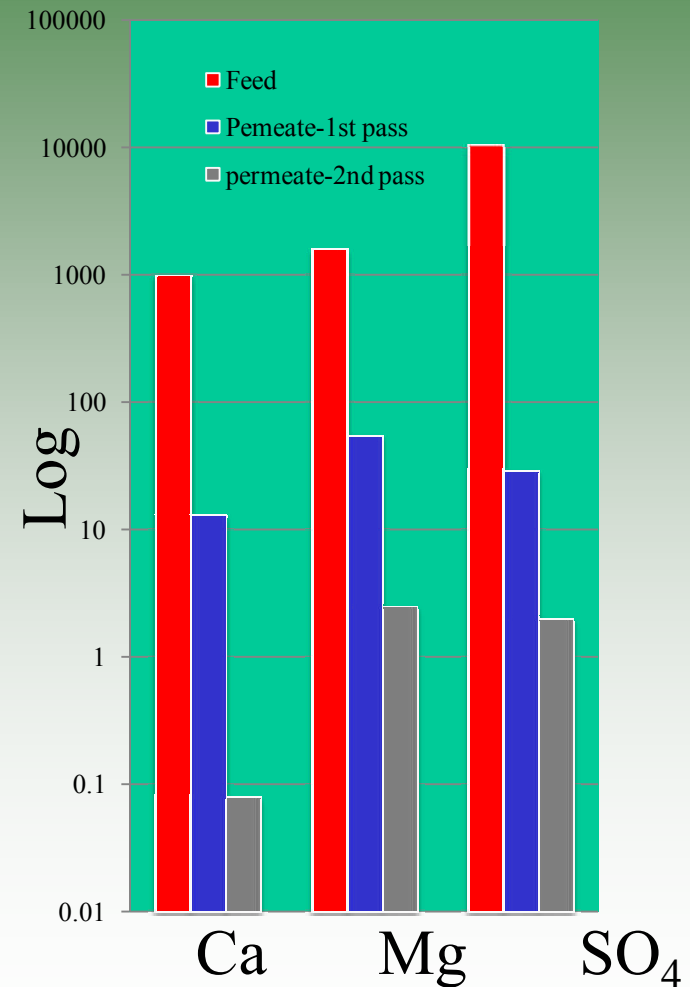


# Applying these criteria suggests a general limit for single-stage RO of ~85,000 TDS



Half of US brines are treatable by seawater methods alone

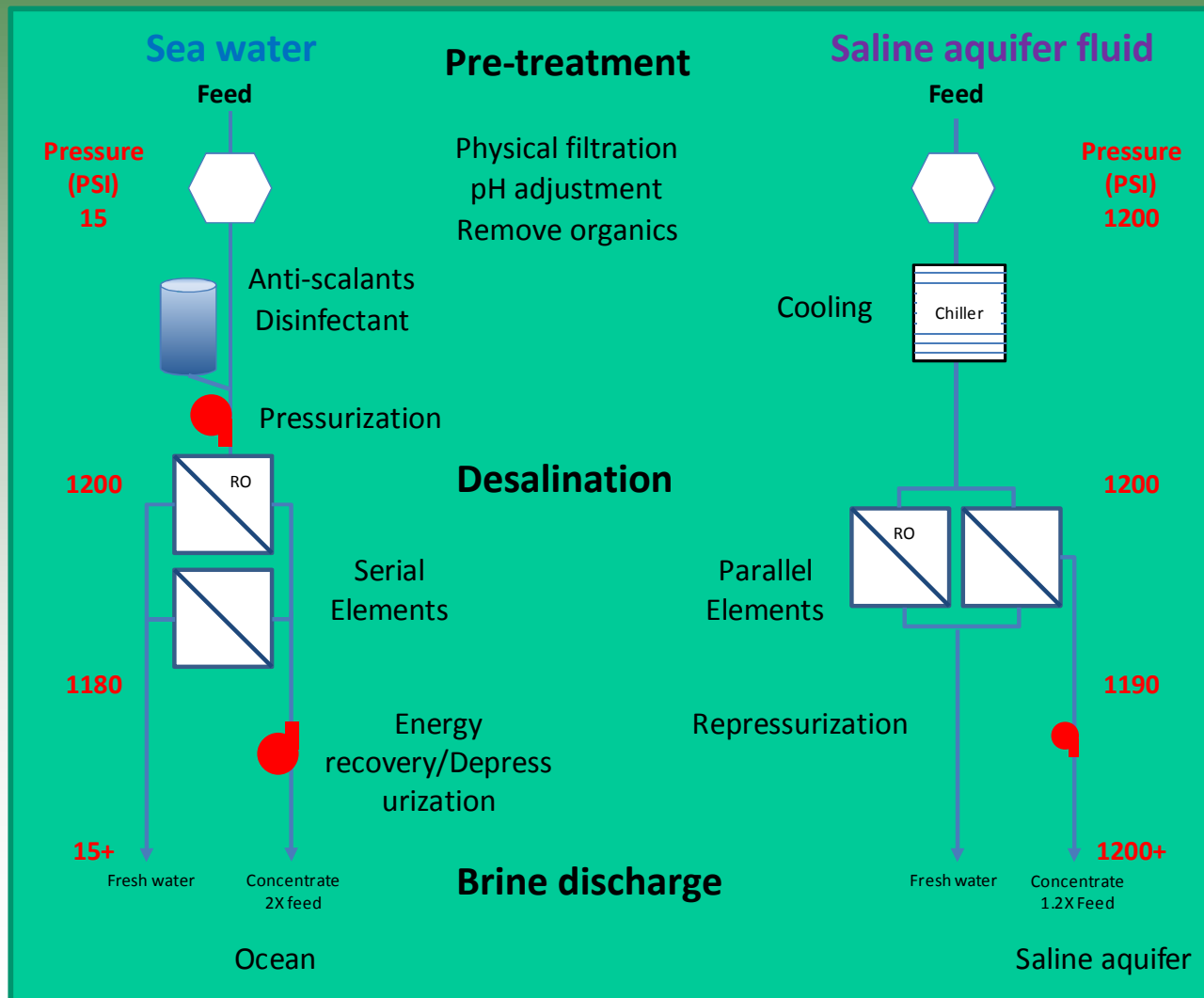
# What about higher TDS? Nanofiltration can efficiently lower hardness and sulfate in brines - this is the next treatment method



# A general categorization of treatment feasibility is based on TDS

- 10,000-40,000 mg/L: Standard RO with  $\geq 50\%$  recovery
- 40,000-85,000 mg/L: Standard RO with  $\geq 10\%$  recovery; higher recovery possible using 1500 psi RO membranes and/or multi-stage incremental desalination likely including NF (nanofiltration)
- 85,000-300,000 mg/L: Multi-stage process (NF + RO using process design that may differ significantly from seawater systems)
- $> 300,000$  mg/L: Not likely to be treatable

# We propose using a modified version of existing seawater desalination technology



Fluid is already pressurized, no need for high P pump

Chill fluid to working range for polymer membranes

Run at high volume-low recovery to reduce operating costs

Small boost in pressure needed for reinjection

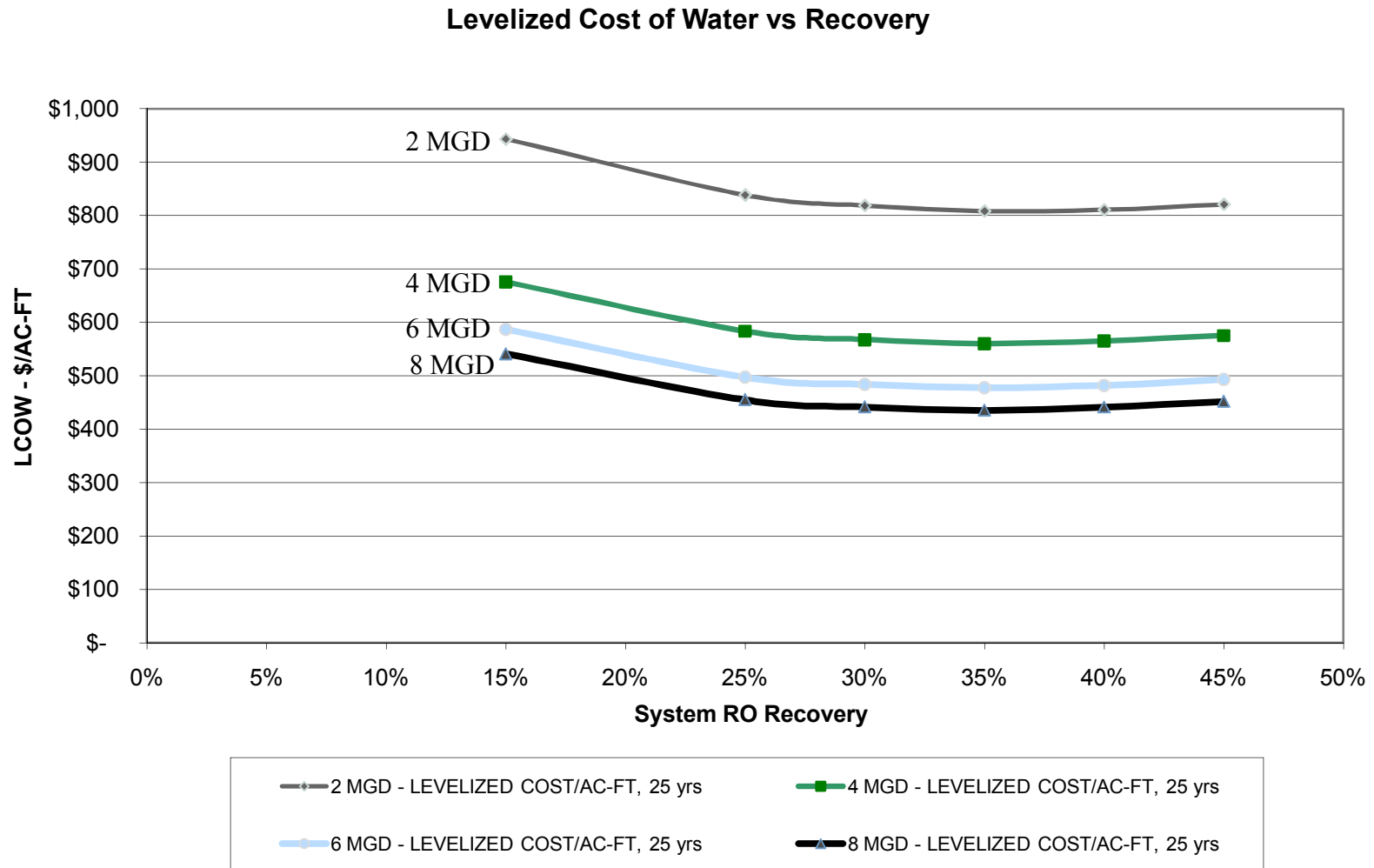
No energy recovery step needed

# Because the operational constraints are different, the optimized system configuration will differ from that of conventional seawater RO

- Energy for desalination comes from the pressurized reservoir
- Unlike conventional sea water desalination systems, there is no energy penalty for low water recovery systems
  - Processing large volumes of water at low recovery can provide the necessary space in the subsurface for CO<sub>2</sub> storage
  - Low recovery RO is favorable in terms of scaling, fouling, driving pressure, and membrane replacement frequency
- The fluid remains pressurized from start (production well) to finish (reinjection back into subsurface)
  - Some pressure is used to power the RO process
- The permeate is partially pressurized, which is useful for transporting it to the user

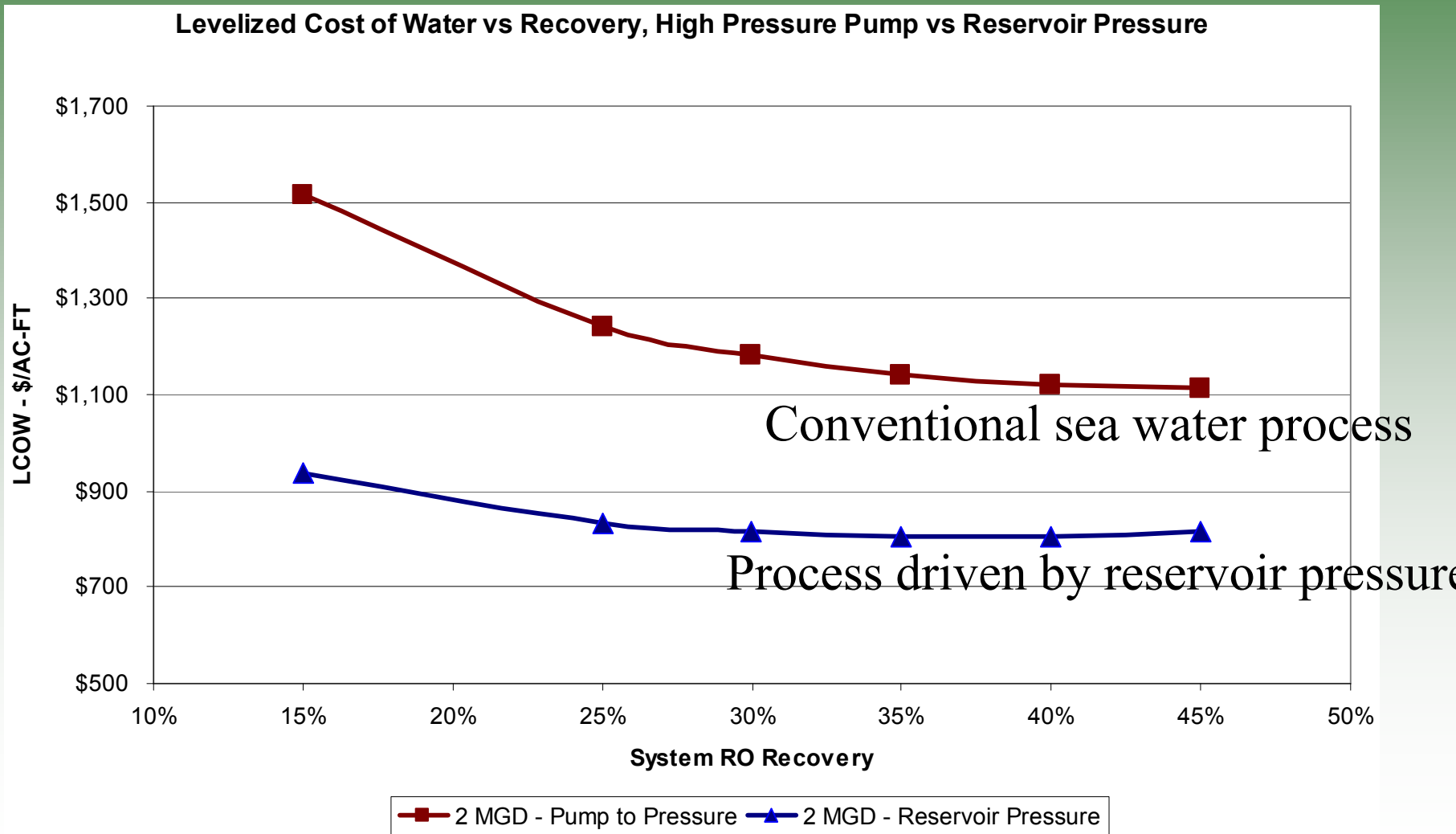


# Cost of water decreases with plant size and is fairly flat with respect to water recovery





# Water costs are relatively low when process energy is supplied by reservoir pressure



# Itemization of costs for 2 and 8 MGD (permeate) water desalination plant at 40% water recovery

Base FEED Flow, MGD	5.00	Product Flow, MGD	2.0	2.0	2.0	2.0	2.0	2.0
Base PRODUCT Flow, MGD	2.00	Recovery, percent	45.0%	40.0%	35.0%	30.0%	25.0%	15.0%
Base Recovery	40%	AC-FT/YR	2,240	2,240	2,240	2,240	2,240	2,240
<b>TOTAL DIRECT OPERATING COSTS</b>	<b>\$/YR</b>	<b>\$</b>	<b>1,240,502</b>	<b>\$ 1,214,833</b>	<b>\$ 1,200,032</b>	<b>\$ 1,200,304</b>	<b>\$ 1,200,168</b>	<b>\$ 1,283,423</b>
	<b>\$/AC-FT</b>	<b>\$</b>	<b>553.81</b>	<b>\$ 542.35</b>	<b>\$ 535.74</b>	<b>\$ 535.86</b>	<b>\$ 535.80</b>	<b>\$ 572.97</b>
INSTALLED CAPITAL COST, \$/GPD		\$	3.47	\$ 3.49	\$ 3.56	\$ 3.71	\$ 3.98	\$ 4.93
TOTAL DIRECT CAPITAL		\$	3,844,576	\$ 3,912,316	\$ 4,027,492	\$ 4,234,852	\$ 4,588,768	\$ 5,823,751
INSTALLED CAPITAL COST		\$	6,934,334	\$ 6,987,133	\$ 7,120,062	\$ 7,414,175	\$ 7,962,181	\$ 9,869,483
NPV of O&M		\$	14,456,293	\$ 14,157,162	\$ 13,984,670	\$ 13,987,844	\$ 13,986,263	\$ 14,956,479
NPV of O&M + Capital Cost		\$	21,390,627	\$ 21,144,295	\$ 21,104,731	\$ 21,402,020	\$ 21,948,444	\$ 24,825,963
NPV of AC-FT/yr			26,103	26,103	26,103	26,103	26,103	26,103
<b>2 MGD - LEVELIZED COST/AC-FT, 25 yrs</b>			<b>\$ 819</b>	<b>\$ 810</b>	<b>\$ 809</b>	<b>\$ 820</b>	<b>\$ 841</b>	<b>\$ 951</b>

Base FEED Flow, MGD	20.00	Product Flow, MGD	8.0	8.0	8.0	8.0	8.0	8.0
Base PRODUCT Flow, MGD	8.00	Recovery, percent	45.0%	40.0%	35.0%	30.0%	25.0%	15.0%
Base Recovery	40%	AC-FT/YR	8,960	8,960	8,960	8,960	8,960	8,960
<b>TOTAL DIRECT OPERATING COSTS</b>	<b>\$/YR</b>	<b>\$</b>	<b>2,251,224</b>	<b>\$ 2,142,985</b>	<b>\$ 2,073,988</b>	<b>\$ 2,061,919</b>	<b>\$ 2,041,722</b>	<b>\$ 2,291,636</b>
	<b>\$/AC-FT</b>	<b>\$</b>	<b>251.26</b>	<b>\$ 239.18</b>	<b>\$ 231.48</b>	<b>\$ 230.13</b>	<b>\$ 227.88</b>	<b>\$ 255.77</b>
INSTALLED CAPITAL COST, \$/GPD		\$	2.58	\$ 2.59	\$ 2.62	\$ 2.72	\$ 2.92	\$ 3.67
TOTAL DIRECT CAPITAL		\$	10,643,981	\$ 10,796,811	\$ 10,996,812	\$ 11,530,415	\$ 12,499,362	\$ 16,138,799
INSTALLED CAPITAL COST		\$	20,629,930	\$ 20,756,123	\$ 20,947,918	\$ 21,757,741	\$ 23,349,555	\$ 29,354,228
NPV of O&M		\$	23,849,500	\$ 22,702,811	\$ 21,971,857	\$ 21,844,001	\$ 21,630,028	\$ 24,277,624
NPV of O&M + Capital Cost		\$	44,479,430	\$ 43,458,933	\$ 42,919,775	\$ 43,601,742	\$ 44,979,583	\$ 53,631,852
NPV of AC-FT/yr4		AC-FT/Period	94,920	94,920	94,920	94,920	94,920	94,920
<b>8 MGD - LEVELIZED COST/AC-FT, 20 yrs</b>			<b>\$ 469</b>	<b>\$ 458</b>	<b>\$ 452</b>	<b>\$ 459</b>	<b>\$ 474</b>	<b>\$ 565</b>

# Input parameters for economic analysis

<b>Fixed parameters:</b>		
Assumed Discount Rate	7.00%	
Base Operating Pressure at reference conditions	1,200	psi
Operating Cost escalation, %/yr	0.00%	
Cleaning	2	Times/year
<b>Variables:</b>		
Base water recovery	40%	10-50
Plant Lifetime / Evaluation Period, yrs	25.00	20 and 25 years
<b>Consumables:</b>		
Activated Carbon	\$ 30	\$/ft <sup>3</sup>
Chemicals	\$3	\$/lb.
Filter cartridges	\$ 4	\$/each
Power, Repressurization	\$0.07	\$/kWh
Power. Misc uses	200.00	kWh/day
<b>Labor:</b>		
Fringe & Overhead Multiplier	2.00	factor
Supervisor	\$ 150,000	Salary
Operators	\$ 60,000	Salary
Technicians	\$ 75,000	Salary
<b>Other:</b>		
Mechanical Maintenance, % of Capital	3%	
Length of high pressure piping	125	ft

# How much water?

- This method is limited to the volume of water displaced by the injected CO<sub>2</sub>.

6 million tonnes CO<sub>2</sub> = 8 million m<sup>3</sup> water

- ✓ 6000 acre-feet
- ✓ Serve 10,000 homes
- ✓ Irrigate 2000 acres cropland
- ✓ Provide half the total water usage for a 1 GW IGCC

# This process has favorable impacts on reservoir storage of CO<sub>2</sub> – Tom will tell you more

- Reduces the energy needed for CO<sub>2</sub> injection because reservoir pressure is decreased through water withdrawal
- Recovers some of the energy used for CO<sub>2</sub> injection by powering the desalination process using reservoir pressure
- Allows the reservoir pressure field, and in particular the location of the CO<sub>2</sub> plume, to be manipulated through strategic injection of CO<sub>2</sub>, production of formation brine, and reinjection of residual brine
- Lowers the risk of geological carbon storage by providing a method to control the reservoir pressure field

# Conclusions

- Many saline formation waters appear to be amenable to largely conventional RO treatment
- Thermodynamic modeling indicates that osmotic pressure is more limiting on water recovery than mineral scaling.
- The use of thermodynamic modeling with Pitzer's equations (or Extended UNIQUAC) allows accurate estimation of osmotic pressure limits
- A general categorization of treatment feasibility is based on TDS has been proposed, in which brines with 10,000-85,000 mg/L are the most attractive targets
- Brines in this TDS range appear to be abundant (geographically and with depth) and could be targeted in planning future CCS operations (including site selection and choice of injection formation)
- The estimated cost of treating waters in the 10,000-85,000 mg/L TDS range is about half that for conventional seawater desalination, due to the anticipated pressure recovery

# Future Plans

- Evaluate high TDS options ( $>85,000$ )
- Test method on actual brine from partnership site
- Begin looking at reservoir operational issues

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